

66035
Ancient Regolith Breccia
211.4 grams

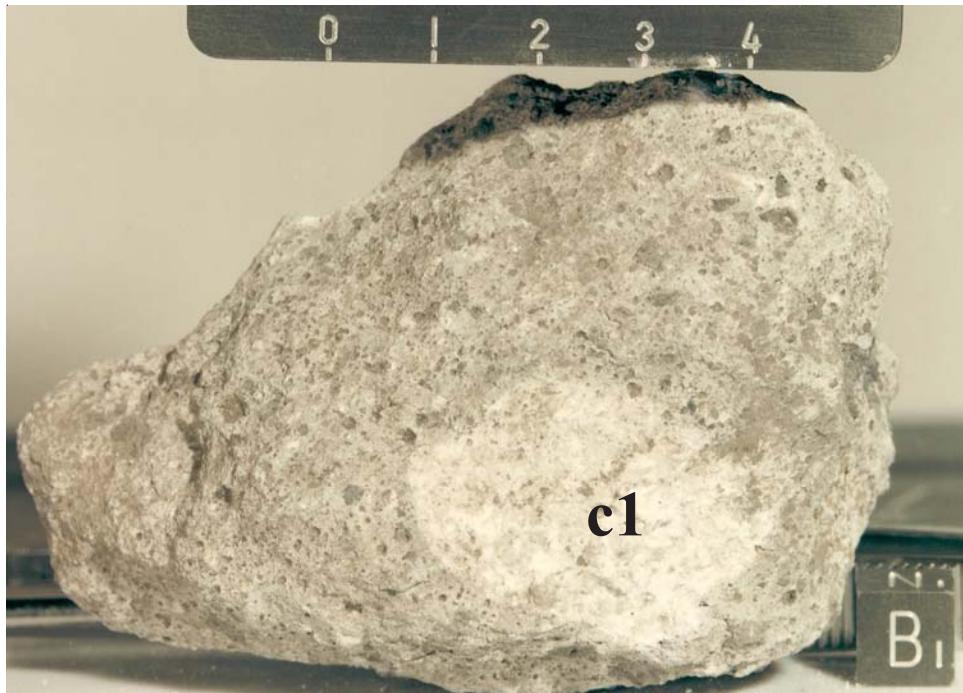


Figure 1: Photo of 66035 showing large caaelastic anorthosite clast (c1). Cube and scale are in cm. S72-39662.



Figure 2: Photo of 66035. Cube is 1 cm. S72-39665.



Figure 3: Photo of thin section of 66035, 5. S72-43566. About 1 cm across.

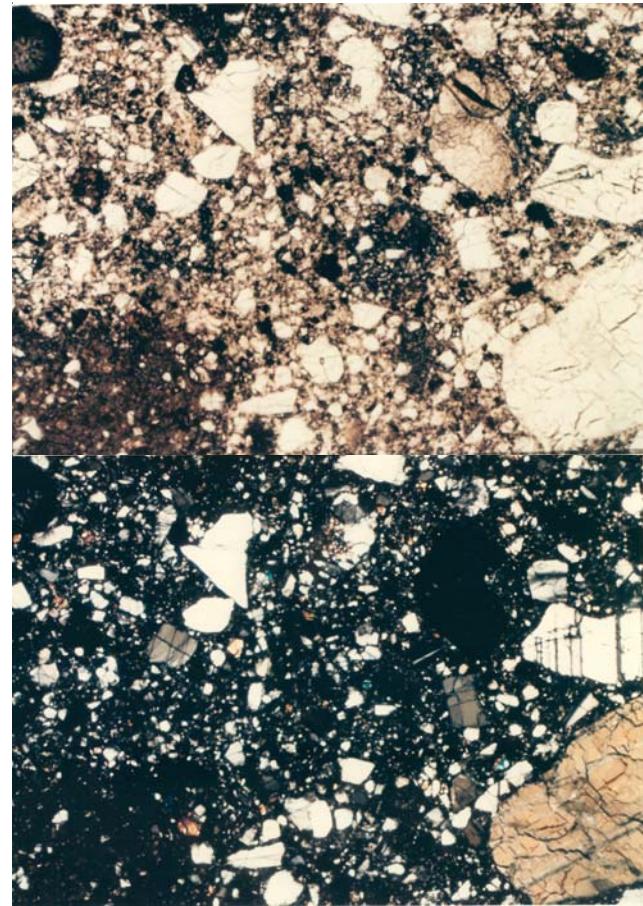


Figure 4: Photomicrographs of thin section of matrix of 66035 showing abundant glass. a) top is plane polarized light S72-42258, b) bottom is crossed-polarized light S72-42259.

Introduction

66035 is from the base of Stone Mountain, Apollo 16. It was collected near 66055 and has some characteristics of 66055, but it is a regolith breccia, while 66055 is not.

66035 has zap pits on all surfaces, so must have “rolled or jumped” on the regolith.

Mineralogical Mode for 66035

(from McKay et al. 1986) (“Optical”)

	>500 micron	20-500 micron
Mare basalt	0	0
KREEP basalt	1.2	3.2
Plutonic rock frag.	94	8.1
Other lithic	0	7.5
Granulite	0	0
Poik. Rocks	1.8	8.8
Subophitic	0.9	7.5
Intergranular	0	3
Intersertal	0	0.3
Vitric breccia	0	1
Frag. Breccia	0	0
Plagioclase	0	41.4
Olivine	0	8.5
Pyroxene	0	2.7
Opaques	0	0
Glass	0.9	13.9
Agglutinate	0	1.1

Mineralogical Mode for 66035

(from Simon et al. 1988)

	20-90 micron	90-1000 micron
Matrix < 20 micron	34.9 %	
Mare basalt	0	0
KREEP basalt	0	0
Feldspathic basalt	0	0
Plutonic rock frag.	0	0.4 %
Granulite	0	0.2
Poik. rocks	0.2	4.7
Impact melts	0.7	6
Regolith brec.	0	1
Agglutinate	0.3	1.6
Plagioclase	14.6	17.3
Olivine	1.3	0.1
Pyroxene	1.7	0.3
Opaques	0.1	0
Glass	2.2	4

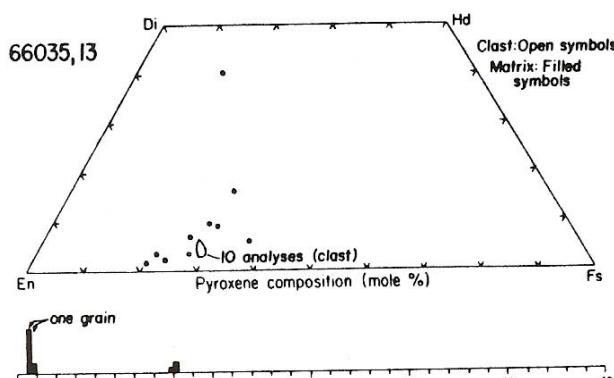


Figure 5: Pyroxene composition of c1 (Warren and Wasson 1979).

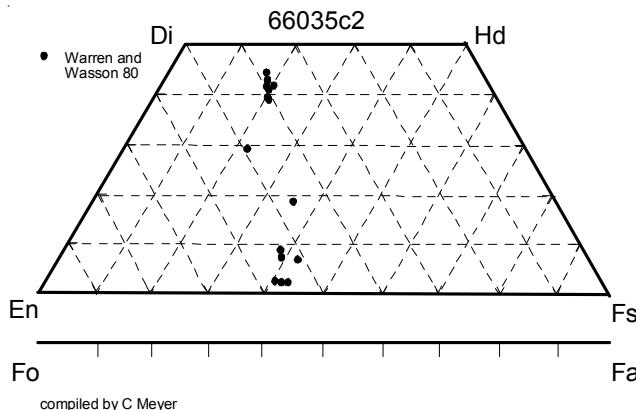


Figure 6: Pyroxene composition of c2 (Warren and Wasson 1980).

glasses to crystalline poikilitic and subophitic rocks.

James (1981) and Fruland (1983) identified 66035 as a regolith breccia. Consequently, McKay et al (1986) and Simon et al. (1988) included 66035 in their study of regolith breccias. The maturity index (Is/FeO) is low, but the rare gas content is high.

Quick et al. (1978) describe 66075, which is presumably a companion rock to 66035.

Significant clasts

c1 Large Cataclastic Anorthosite ,12 ,13TS

This is the large (3.5 cm) clast seen in figure 1. However, it was only “skin deep” and there is not a lot of mass. It is ~95% plagioclase ($An_{94.95}$), 5% pyroxene ($Wo_{2-6}En_{66-68}Fs$), but it is not pristine. According to

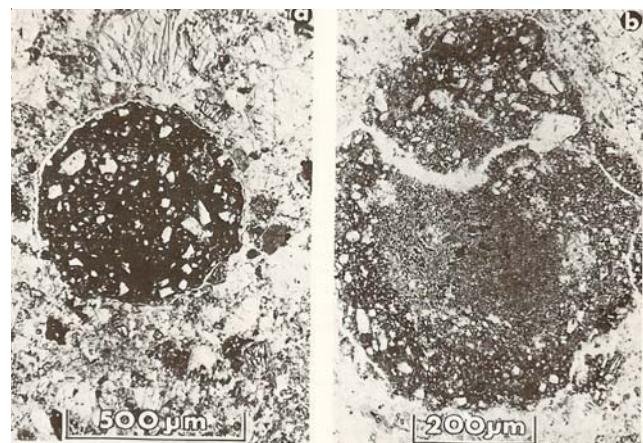


Figure 7: Photo of clasts in 66035 (from Grieve et al. 1974).

Warren and Wasson (1978) it has a “granulitic” texture, but Ryder and Norman (1980) termed it “granoblastic noritic anorthosite”. The REE are shown in figure 10 and the pyroxene composition is shown in figure 5.

c2 Coarse-grained Norite ,18 ,22TS

This clast was seen by PET who described the abundant pyroxene as honey-brown. It is ~58% plagioclase (An_{97}), pyroxene (En_{57}) (figure 6) and plots within the field of “ferroan anorthosite”. However, it also has significant Ir and Au (contamination?) (table).

Porous Olivine: Fo_{97} with 1.2% Ca_2SiO_4 of meteoritic origin (Warren and Wasson 1979).

Granitic Glass: Grieve et al. (1974) reported several clasts of granitic glass (table 3) – significant because the same thing is found in 66055.

Chemistry

The composition of the matrix of 66035 has been reported by Korotev (1990), McKay et al. (1986) and Simon et al. (1988). Eldridge et al. (1973) obtained a measure of K, U and Th, for the bulk rock, in agreement with the data for the matrix. Warren and Wasson reported data for the clasts.

Radiogenic age dating

Cohen et al. (2007) dated a clast by Ar/Ar (with poor precision).



Figure 8: Photo of 66035 showing clasts. Cube is 1 cm. S72-39664.



Figure 9: Photo of 66035 showing clast. Cube is 1 cm. S72-39663.

Cosmogenic isotopes and exposure ages

Eldridge et al. (1973) reported the cosmic ray induced activity of $^{26}\text{Al} = 136 \text{ dpm/kg}$ and $^{22}\text{Na} = 42 \text{ dpm/kg}$.

Summary of Age Data for 66035

Ar/Ar
Cohen et al. 2007 3956 +/- 579 m.y.

Other Studies

The rare gas content and isotopic ratios are given in Mckay et al. (1986).

Processing

66035 had not been sawn (as of 2009). The clasts were sampled by chipping. There are 17 thin sections.

Table 1. Chemical composition of 66035.

reference weight SiO ₂ %	McKay86	Korotev96	Simon88	Warren80 clast c2	Warren 79 clast c1	Warren 78 ,12 clast	Eldridge73
TiO ₂	0.43		0.66	(a) 0.27	0.84	0.67	
Al ₂ O ₃	28.5		30	(a) 19.6	29.8	31	29.8 (a)
FeO	4.85	4.69	4.15	(a) 10.9	3.21	2.83	3.22 (a)
MnO			0.053	(a) 0.16	0.04	0.033	0.04 (a)
MgO	5.25		4.6	(a) 8.8	4.64	3.81	4.64 (a)
CaO	16	15.6	15.2	(a) 12.6	16.8	17.2	16.8 (a)
Na ₂ O	0.442	0.474	0.5	(a) 0.22	0.41	0.43	0.41 (a)
K ₂ O			0.096	(a) 0.02	0.016	0.01	0.016 (a) 0.092 (b)
P ₂ O ₅							
S %							
<i>sum</i>							
Sc ppm	9.26	7.25	6.5	(a) 23.1	2.3	3.1	2.32 (a)
V	20		14	(a)			
Cr	700	673	501	(a) 1400	250	240	25.2 (a)
Co	18.6	25	25.7	(a) 19.5	7.8	7.1	7.8 (a)
Ni	214	354	370	(a) 52	20.4	6	20.4 (a)
Cu							
Zn				3.2	1.03	0.82	1.03 (a)
Ga					4.1	4.5	4.1 (a)
Ge ppb				195	72	48	72.4 (a)
As							
Se							
Rb			1.6	(a)			
Sr	187	183	110	(a)			
Y							
Zr	150	214	140	(a) 220			
Nb							
Mo							
Ru							
Rh							
Pd ppb							
Ag ppb							
Cd ppb					19	21	19 (a)
In ppb					4.3	1.3	4.3 (a)
Sn ppb							
Sb ppb							
Te ppb							
Cs ppm	0.1		0.14	(a)			
Ba	101	150	120	(a) 113	21	17	21 (a)
La	9.08	15.6	11.3	(a) 1.88	0.58	0.54	0.58 (a)
Ce	24.5	40.1	29.5	(a) 4.6	1.1	1.3	1.1 (a)
Pr							
Nd	14		18.5	(a) 6			
Sm	4.23	6.93	5.09	(a) 0.89	0.22	0.2	0.22 (a)
Eu	1.095	1.23	1.24	(a) 0.68	1.09	0.95	1.09 (a)
Gd			6.3	(a)			
Tb	0.81	1.41	1.04	(a) 0.24		0.054	(a)
Dy			7.6	(a)			
Ho			1.4	(a)			
Er							
Tm							
Yb	2.97	4.92	3.5	(a) 1.11	0.2	0.27	0.2 (a)
Lu	0.424	0.669	0.47	(a) 0.18	0.026	0.036	0.026 (a)
Hf	3.26	5.27	3.6	(a) 0.53		0.15	
Ta	0.39	0.57	0.41	(a) 0.14			
W ppb							
Re ppb				0.099	0.06	0.11	0.06 (a)
Os ppb							
Ir ppb	4.4	8.3	5.5	(a) 1.04	0.3	0.9	0.3 (a)
Pt ppb							
Au ppb	4.5	7.8	1.4	(a) 0.8	0.132	0.14	0.132 (a)
Th ppm	1.77	2.5	1.52	(a) 0.17			
U ppm	0.38	0.67	0.51	(a) 0.6			1.87 (b) 0.49 (b)

technique: (a) INAA, (b) radiation counting

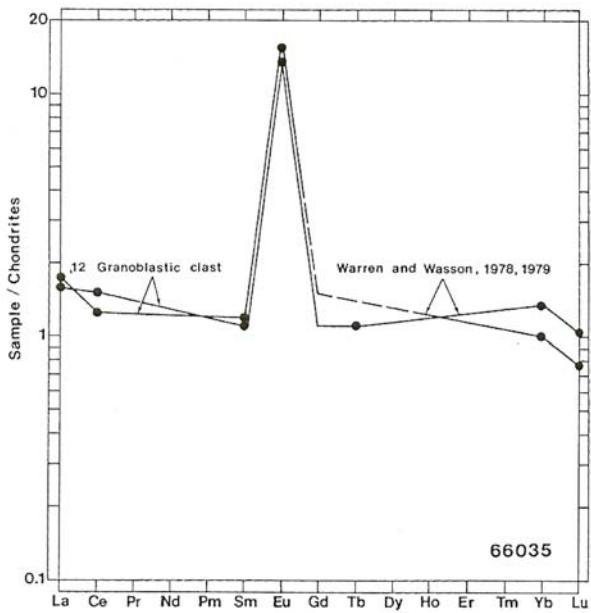
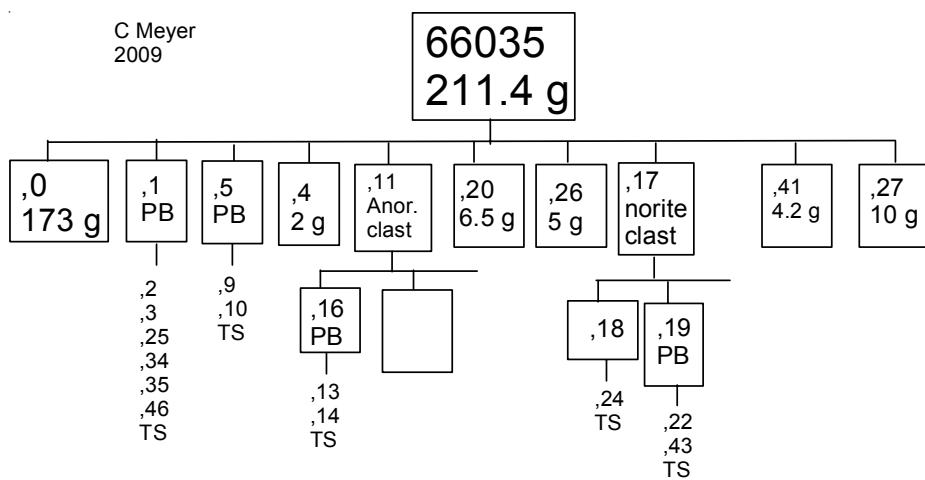


FIGURE 4. Rare earths.

Figure 10: Compsosition of clast "c1".

Table 2: Glass compositions in 66035.

Grieve et al.1974																Shearer 1990			
1	2	3	4	5	6	10	11	12	13	14	15	16	17	18	19	Wentworth 1988			
SiO ₂	71.25	56.69	63.94	57.68	44.89	43.38	49.77	43.55	44.94	44.1	44.17	47.48	47.31	48.5	48.9	(a)			
TiO ₂	0.58	1.18	2.83	0.98	0.01	0.03	1.13	2.99	2.62	1.74	2.49	0.92	1.27	0.7	1.56	(a)			
Al ₂ O ₃	12.35	6.76	11.52	17.05	35.62	33.36	20.84	22.43	17.87	14.77	14.77	22.74	19.79	23.46	18.8	(a)			
FeO	5.67	30.23	10.4	7.77	0.14	0.88	2.28	4.04	6.27	5.07	7.77	6.73	8.42	2.1	0.52	(a)			
MnO	0.11	0.4	0.14	0.11	0.01	0.02	0.27	0.04	0.1	0.05	0.11	0.1	0.11	0.9	0.17	(a)			
MgO	0	0.57	1.73	4.12	0	1.33	8.44	12.96	16.05	17.4	20.65	7.79	9.22	10.44	10.58	(a)			
CaO	1.99	1.44	5.81	8.4	18.74	18.71	12.54	13.2	10.52	11.34	8.29	13.66	12.03	14.83	16.72	(a)			
Na ₂ O	2.43	0.05	0.11	1.12	0.28	0.77	1.2	0.05	0	0.06	1.26	0.16	0.67	0.24	1.26	(a)			
K ₂ O	5.39	2.65	4.49	2.25	0.01	0.01	2.14	0.07	0	0.01	0.27	0	0.35	0.05	0.5	(a)			
P ₂ O ₅														0.01	0	(a)			
Zr														256	768	(b)			
Ba														128	986	(b)			
La														16	68	(b)			



References for 66035

- Bersch M.G., Taylor G.J., Keil K. and Norman M.D. (1991) Mineral compositions in pristine lunar highland rocks and the diversity of highland magmatism. *Geophys. Res. Letters* **18**, 2085-2088.
- Butler P. (1972) Lunar Sample Information Catalog Apollo 16. Lunar Receiving Laboratory. MSC 03210 Curator's Catalog. pp. 370.
- Cohen B.A., Symes S.J. and Swindle T.D. (2006) Petrography and chemistry of impact-melt clasts in Apollo 16 breccias (abs#1379). *Lunar Planet. Sci. XXXVII*, Lunar Planetary Institute, Houston.
- Cohen B.A., Symes S.J., Swindle T.D., Weirich J. and Isachsen C. (2007) Ages of Impact-melt clasts in Apollo 16 breccias (abs#1006). *Lunar Planet. Sci. XXXVIII*, Lunar Planetary Institute, Houston.
- Eldridge J.S., O'Kelley G.D. and Northcutt K.J. (1973) Radionuclide concentrations in Apollo 16 lunar samples determined by nondestructive gamma-ray spectrometry. *Proc. 4th Lunar Sci. Conf.* 2115-2122.
- Fuland Ruth M. (1983) Regolith Breccia Workbook. Curatorial Branch Publication # 66. JSC 19045.
- Grieve R.A.F., Plant A.G. and Dence M.R. (1974) Lunar impact melts and terrestrial analogs: Their characteristics, formation and implications for crustal evolution. *Proc. 5th Lunar Sci. Conf.* 261-273.
- Hunter R.H. and Taylor L.A. (1981) Rust and schreibersite in Apollo 16 highland rocks: Manifestations of volatile-element mobility. *Proc. 12th Lunar Planet. Sci. Conf.* 253-259.
- James O.B. (1981) Tentative classification of the Apollo 16 breccias (abs). *Lunar Planet. Sci. XII*, 506-508.
- Korotev R.L. (1996c) On the relationship between the Apollo 16 ancient regolith breccias and feldspathic fragmental breccias, and the composition of the prebasin crust in the Central Highlands of the Moon. *Meteor. & Planet. Sci.* **31**, 403-412.
- McKay D.S., Bogard D.D., Morris R.V., Korotev R.L., Johnson P. and Wentworth S.J. (1986) Apollo 16 regolith breccias: Characterization and evidence for early formation in the megaregolith. *Proc. 16th Lunar Planet. Sci. Conf.* in J. Geophys. Res. 91, D277-D303.
- Quick J.E., Brock B.S. and Albee A.L. (1978) Petrology of Apollo 16 breccia 66075. *Proc. 9th Lunar Planet. Sci. Conf.* 921-939.
- Ryder G. and Norman M.D. (1980) Catalog of Apollo 16 rocks (3 vol.). Curator's Office pub. #52, JSC #16904
- Shearer C.K., Papike J.J., Galbreath K.C., Wentworth S.J. and Shimizu N. (1990b) A SIMS study of lunar "komatiitic glasses". Trace element characteristics and possible origin. *Geochim. Cosmochim. Acta* **54**, 1851-1857.
- Simon S.B., Papike J.J., Laul J.C., Hughes S.S. and Schmitt R.A. (1988) Apollo 16 regolith breccias and soils: Recorders of exotic component addition to the Descartes region of the moon. *Earth Planet. Sci. Lett.* **89**, 147-162.
- Warner J.L., Simonds C.H. and Phinney W.C. (1973) Apollo 16 rocks: Classification and petrogenetic model. *Proc. 4th Lunar Sci. Conf.* 481-504.
- Warren P.H. and Wasson J.T. (1978) Compositional-petrographic investigation of pristine nonmare rocks. *Proc. 9th Lunar Planet. Sci. Conf.* 185-217.
- Warren P.H. and Wasson J.T. (1979a) The compositional-petrographic search for pristine nonmare rocks: Third foray. *Proc. 10th Lunar Planet. Sci. Conf.* 583-610.
- Warren P.H. and Wasson J.T. (1980a) Further foraging of pristine nonmare rocks: Correlations between geochemistry and longitude. *Proc. 11th Lunar Planet. Sci. Conf.* 431-470.
- Warren P.H. and Kallemeyn G.W. (1984) Pristine rocks (8th foray): Plagiophile element ratios, crustal genesis, and the bulk composition of the Moon. *Proc. 15th Lunar Planet. Sci. Conf.* in J. Geophys. Res. 89, C16-C24.
- Warren P.H. (1993) A concise compilation of petrologic information on possibly pristine nonmare Moon rocks. *Am. Mineral.* **78**, 360-376.
- Wentworth S.J. and McKay D.S. (1988) Glasses in ancient and young Apollo 16 regolith breccias: Populations and ultra-Mg glass. *Proc. 18th Lunar Planet. Sci. Conf.* 67-77. Lunar Planetary Institute, Houston.